Gaian Control of Climate During the Archean Era

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Today, the two main greenhouse gases in Earth's atmosphere are CO2 and H2O. The CO2 concentration is controlled primarily by the inorganic carbonate-silicate cycle over long time scales, and so the effect of the biota on climate appears to be rather small. During the Archean Era, however, the situation may have been quite different. Methane could have been a major greenhouse gas at times when atmospheric O2 concentrations were low. Unlike the case for CO2, the dominant source of methane is biological. Specifically, methanogenic bacteria (methanogens) living in anaerobic environments domi-nate methane production today and probably did so in the past as well. Biotic innovations could therefore have influenced climate to a much greater extent in the Archean than they do today, creating a "Gaian" climate control system (1). Detailed models suggest the following scenario: Methane became an important constituent of the atmosphere as soon as methanogens evolved, probably during the early Archean, or even Hadean Era (2). CH4 concentrations of several percent or more are pos-sible, especially if hydrogen escape was slow (3). Temperatures of 70oC or higher appear plausible—enough to explain the predominance of hyperthermophiles near the base of the evolutionary rRNA tree. The origin of anoxygenic photosynthesis, also during the early Archean, would have drawn CH4 levels down by increasing primary productivity and sequestering more outgassed hydrogen in sediments (2). The origin of oxygenic pho-tosynthesis, sometime around 3.0 Ga (4), had complex effects. Initially, CH4 levels may have increased, assuming that O2 was consumed while much of the organic matter de-cayed to produce CH4 (5). We suggest here, however, that atmospheric O2 increased briefly around 2.7-2.9 Ga, driving CH4 levels down and triggering the Witwatersrand glaciations (6). The evidence for this comes from sulfur isotopes in Archean rocks, which exhibit mass-independent fractionation before and after this time, but not during it (7). O2 levels decreased and CH4 went up again in the Late Archean, based on S isotope data (8). At ~2.4 Ga, O2 went up for good, triggering the Paleoproterozoic glaciations (9).

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